in August alone. The seasonal distribution in the average case parallels the course of mean maximum temperatures, though fires tend to lag behind temperature.

This great seasonal concentration of fires, of course, tends to make suppression difficult, because so many fires occur at one time. The most striking evidence of the difficulty of successfully handling lightning fires is found in the fact that exceptional storms have set in a single day as many as 340 fires. I have classified storms into four general groups, those causing less than 50 fires, those with from 51 to 150 fires, those with from 151 to 250 fires, and those with over 250 fires. In handling fires resulting from storms of the first three classes we have been uniformly successful in holding the size of the average fire to about 35 acres, the figures for each class being 49, 29, and 34. In other words, though many fires result from these generally local storms, our protection organization is equipped to handle the situation.

For the three great general storms which have set over 250 fires, the situation is, however, radically different. Fires from these storms attained an average size of 312 acres, over eight times as great as from storms of the other classes. The largest fires known in northern California resulted from these catastrophes.

In practice, a general electrical storm, such as these, results in what may be regarded as an overload of business. We are not equipped to handle all fires promptly, and must rely on cooperative help, which is not always satisfactory. One of the most important contributions that could be made to organized fire protection in California, and, indeed, throughout the West, would be prediction, even a few hours in advance of the occurrence of these great general storms. We could then do much of the emergency organization work, which must now wait until fires are actually set.

Lightning fires individually are generally not particularly difficult to handle, but in bunches they represent perhaps the most severe test that fire protection forces must meet. During the past decade, on the average, 42 per cent of the entire crop of lightning fires for an entire season have occurred in a single storm, further evidence of the extreme concentration of this form of fire business.

I have spoken briefly of the when and how of lightning fires, and I should now like to speak of the where. We have plotted on a State map the point of origin of each fire for a period of 10 years. Even the most casual study shows that as a matter of recorded experience there are both well-marked lightning centers, and what may, I think, be fairly regarded as lightning zones. It seems evident:

1. That from north to south in the Coast Range, the belt generally decreases in width.

2. The same general trend is apparent in the Sierra Region.

3. In southern California the zones are generally narrower than elsewhere.

In intensity, or number of fires per unit of area, there is a general, though by no means regular, decrease from north to south.

This analysis of the place of occurrence of lightning fires has proved of great value in helping us to most effectively place our men, to organize detection service, etc. On the map there are many blank spots for which no explanation can now be offered. Whether they are purely accidental and will be filled in as more data accumulate is open to question. They may conceivably be out of the principal storm tracks.

This is the lightning fire zone in general. When we analyze the great storms, we find that they cover pretty much the same region. This is not true in detail, but the limit of southerly extension, for example, has been about the same for all three. The national forests to the south are subject to intense storms, but so far have not participated in the most extensive storms. This it seems is a point worthy of cooperative study.

This, then, is the situation in regard to lightning fires in the forests of California. Obviously enough, the greatest contribution to better handling of them would be the ability to predict the occurrence, particularly of the great general storms. It is probably true that these storms are intimately related to the general weather condition and can be predicted, given sufficient study of the problem. The more local convectional storms are also worthy of attention. Undoubtedly lightning storm centers exist, where storms form repeatedly and from which they travel. One such center is certainly the Sierra Valley, another is the region around Mount Shasta.

For three years now the Forest Service has been utilizing its fire lookout men as recorders of the occurrence and movements of storms. Hundreds of observations have been made, and an analysis of this mass of data will doubtless prove of value. If it is found that storms forming in a particular center tend to travel in a given direction, it will be possible to phone ahead of the storm, and thus to make predictions at least a few hours in advance. Similar data have been secured for the past two seasons in Idaho, Montana, Washington, and Oregon, as well as in California, and suggestive leads for further investigation have already been uncovered.

More study, I believe, is needed of the occurrence of lightning storms in relation to general weather conditions. Cooperative study of this phase of the problem should certainly be of value. In general, the securing of field data is probably the most serious difficulty to be overcome in realizing our goal of prediction of lightning storms. It seems to me not beyond the possible that the field men of the Forest Service, particularly our lookouts, may prove to be ideally situated for that purpose.

HOW WEATHER FORECASTING CAN AID IN FOREST FIRE CONTROL.[1]

By HOWARD R. FLINT.

The title subject given above is one so little discussed by those most concerned that one might almost be led to believe that it had been forbidden by a perpetuation of the drastic forest laws of the time of the Norman Conquest or by the merry days of Robin Hood, when an eye or a right forefinger and thumb of the skilled but unhappy archer was the price paid for a minor transgression of the laws of the king's forest. Of course no such taboo has actually existed, but natural conservatism and inertia have ever been about as effective as written legislation in retarding inevitable progress. The result has been a failure on the part of the average forester to make full use of a tool which may be of great use to him.

Ten years ago the average forester would probably have dismissed the subject with the ironic remark that anyone could tell when he was going to have a fire by the absence of rainfall for a fortnight, and that knowing

[1] Presented at meeting of American Meteorological Society, Los Angeles, Calif., Sept. 19, 1923.

in advance when fires would occur would be of little assistance in any event, since they must be met and put out whenever and wherever they occurred.

To-day we find practical foresters, the men who must form the fire-protection organization and build up the fire-suppression machines, consulting daily weather forecasts and, to some extent at least, permitting their judgment to be influenced by what used to be termed the "weather man's guess." These foresters have guessed the weather themselves and are learning by experience that the weather man's "guess" with its present scientific foundation is correct a large and an increasing percentage of the time. They are learning that it is a tool the possibilities of which have only begun to be developed.

Telephone, telegraph, and radio communication, supported by real organization and the spirit of helpful cooperation, make it possible to put the words of the weather forecaster in Chicago or San Francisco in the most remote and isolated ranger headquarters in the northern Rocky Mountains within an hour or two of the time the forecast was formulated. Truly this is magic, and with its aid the matter of fact forester can hope, not to beat Nature at her own game, but to sit in at a game with Nature aided by cards stacked in advance and with better than an even chance winning of a hard contest.

In order that there may be left in the minds of those present no lurking shade of doubt concerning the magnitude and practical importance of the forest-fire problem, it seems advisable to quote a few statistics borrowed from the official records of the northern Rocky Mountain district of the United States Forest Service. This is one of the several important forest regions of the United States. It includes about 40,000,000 acres of land better adapted to the growth of forest trees than any other known crop. It is naturally a region well endowed for the production of wood, but at this time the travels and researches of foresters have revealed no other region in which forest fires are of more frequent occurrence or in which they are more intensive and completely destructive. This condition is due chiefly to the peculiar climatic and vegetative conditions which will be discussed later.

Of the northern Rocky Mountain region 22,000,000 acres are in the national forests. For the past 15 years rather complete and detailed fire researches have been kept for this vast area. There have occurred in that time 18,169 fires of record. They have covered a total area of 4,400,000 acres, some of which, however, has burned over twice, and a little of it three times during the period. More than ten and a half billion feet of merchantable timber has been killed, only a trifling amount of which has been or can be salvaged. The actual money value of the losses has been conservatively estimated at $27,000,000, a staggering sum, and the cost of fighting fires has been over five and a half million dollars. These figures are for national forest lands alone. The losses on private lands in the region have been fully as great, probably greater in proportion to the acreage involved. 88 per cent of all the loss occurred in two seasons, 1910 and 1919, and 53 per cent of the expenditures for fire suppression, was made in these two seasons in a period of about 90 days each. The climate in most of this region is of the Pacific coast type, with the extremes accentuated by the altitude and distance from the ocean. The summers are characterized by extremely low precipitation in June, July, and August, desiccating southwest winds from the semidesert region along the Columbia and Snake Rivers, and very low relative humidities. During July and August storms frequently pass over this region with little or no precipitation, but accompanied by violent electrical discharges. In the season of 1920 an unusually bad one in that respect, 1,281 fires of record were caused by lightning alone. More than 200 of these were set in the national forests of northern Idaho in a single day. The dominant forest growth of the region is made up of coniferous trees—pines, firs, and others—usually in thick stands and having rather dense crowns; foliage that carries a high content of inflammable resins; and bark and wood that burns freely when ignited.

From the standpoint of forest-fire protection the combination forms a most difficult condition and the destructible resources at stake are valued at $140,000,000 in direct tangible values, not to mention other values which can not well be calculated at present.

It is conceivable that a sufficiently large force of men might be placed and held in this region at all times during the summer to cope effectively with any fire situation which might arise. It is apparent that the cost of such an organization would be enormous. It would be useful for that purpose only three months of each year and would necessarily be forced to seek other occupation during the balance of the year. At this time it does not seem possible to justify the cost of an organization of that kind. It would soon absorb the entire value of the resources at stake. The alternative, and the policy which is now in effect, is to maintain a skeleton organization which can readily meet the more common situations and swell this organization in time of fire emergency by the employment of a sufficiently large force of temporary emergency help directed by the specially trained and prepared organization.

It is apparent that the success or failure of this scheme will depend very largely on the prompt and accurate recognition of emergency conditions in time to permit of the marshaling of the emergency forces. It can truthfully be said of forestry, "time is essence thereof." This is true in the infinitesmal and in the large, for "minutes count" in getting action on a fire, and it takes about a century to grow a forest. A single fire, due to a slight error in judgment or the elapse of a few precious minutes in getting action, may undo the good work and sound judgment of a century.

With the aid of the facts outlined above it should be possible to visualize in some degree, or at least to imagine, how really dependable and detailed weather forecasts might be of great value in fire-control work.

To begin with, the forester who has going fires in his district could obtain more effective results and make material savings in cash if he knew in advance with a fair degree of certainty just what the weather held in store for him during the next few hours. Will the wind remain the same or will it swell to a gale? Will the relative humidity drop to 10 per cent to-morrow afternoon, or will it be above 50 per cent? Does the distant cloud presage rain within 24 hours, or will it spread ruin in the shape of a score of new lightning fires over the far-flung dry hills of the district? These are "burning questions." Can the weather forecaster answer in advance any or all of them? It should be an inspiration to know that in a number of cases that have been checked up he has answered them in advance, though seldom in the past has there been the organization or the faith to fully utilize the information.

Lightning is the greatest single cause of forest fires in the region we have been discussing. In these days of rapid transportation and instantaneous communication a few hours' warning of the approach of a violent electrical

storm might be of material value. A single fire often costs thousands of dollars. Is it not possible that a dependable warning could be given? The behavior of radio and telephone instruments during and just before electrical storms and the researches of one or two eminent meteorologists all suggest an affirmative answer.

Again, the forest officer must decide, often in the absence of any unusual number of going fires, whether the time is ripe for the expansion of his forces, to the limit, to a moderate degree, or not at all. Past experience is the only true basis for judgment. Accurate and readily available weather records should supplement, or probably I should say supplant, memory in forming the basis for a judgment which may involve thousands of dollars. Can the meteorologist predict a week or a month in advance the probable general trend of the season?

The researches of Huntington, Douglas, Ricard, and others at least suggest that there are undeveloped possibilities in this line. Casual local observations indicate that there may possibly be a very intimate relation between local summer rainfall and the depth of snow on the higher ranges during the months of May and June.

Briefly, in summarizing the idea set forth in the title of this paper, it may be said that there is at least some warrant for the belief that weather forecasting can aid forest-fire control in at least three different ways, namely—

1. By warning through the usual 36-hour forecasts of an approaching change in the weather which will influence the behavior of possible or going fires.

2. By means of special forecasts which will give warning six or more hours in advance of the occurrence of lightning in any given locality.

3. By warnings through long-range forecasts, based on sunspot or other phenomena, of the approach of abnormal seasons comparable to the seasons of 1889, 1910, and 1919 in the northern Rocky Mountain region.

METEOROLOGICAL FACTORS AND FOREST FIRES.[1]

By J. V. HOFMANN.

A gathering of foresters with, and at the invitation of, meteorologists marks the realization of the long-felt need of a close correlation of these natural sciences. This accomplishment leaves behind the cry of the insistent few who were ever urging unity of purpose and cooperation and opens the door to a new era of development that will apply all of the scientific facts to the existing conditions. Meteorological factors and forest development are inseparable in nature, and progress in the establishment of a forestry practice will be measured by the extent that these factors are made inseparable in the study of the sciences. The correlation of the meteorological factors needs no discussion at this meeting, consequently this paper is confined to the individual or collective relation of these factors to the forest conditions.

Although all of the climatic factors are related to the development of the forest, those directly related to the forest fire problems are most important because the control of the fire situation is the greatest question in the conservation of the timber supply. The study of the influence of climatic factors on fire hazard has been continued for two years by the Wind River Experiment Station. These studies have included the effect of all of the meteorological factors on forest fire conditions as well as on the behavior of the fire. Temperature, evaporation, wind and other factors influence the fire hazard, but the relative humidity was found to be the most important factor in the development of a dangerous fire period as well as the most usable factor in actual fire control. * * *

Studies conducted by the Wind River Forest Experiment Station of the effect of relative humidity on forest fires showed that fires did not spread when the relative humidity was above 60 per cent. That they spread very slowly and only in very favorable material when the humidity was between 50 and 60 per cent. When the humidity was between 40 and 50 per cent fires picked up, varying from a few running fires to fires that merely smoked up and did not spread. With a humidity of 30 to 40 per cent fires gained some headway and some rapidly spreading fires occurred. A humidity below 30 per cent caused all fires that were in material that would allow spread at all to gain headway, or spread beyond control. Crown fires occurred when the humidity dropped to 25 per cent or lower. * * *

Unquestionably one of the main causes of our enormous fire losses has been due to the failure to realize how very suddenly forest materials may change from a low degree of inflammability to an extremely high degree of inflammability and convert in a few hours fires which have been smoldering harmlessly for days into raging conflagrations.

A realization of this situation can lead to only one conclusion, that the smoldering fires must be put out immediately while they are small, when they can be handled at small expense and before conditions change. * * *

The season of 1923 has been one of exceptionally low fire hazard in the Pacific Northwest, although on September 12 the deficit in precipitation was nearly 6 inches. Temperature has been high during some periods, but on the whole the relative humidity has been low for only short periods or days. However, a low period of humidity during the first days of September caused the most serious fire period of the year which resulted in many fires that spread rapidly and were beyond the control of the fire fighting forces until September 8 and 9 when the relative humidity remained high again. * * *

The correlation of the meteorological factors and the forest fire hazard that has been discussed in this paper emphasizes the importance of the relative humidity and shows that it is the principal factor that can be used as an index of the fire conditions as well as its direct use in fire control.

With this fact established it is evident that the greatest need in forest fire prevention and control is a knowledge of changes in relative humidity as far in advance as possible.

Recognizing this point, the Wind River Experiment Station is now conducting studies to determine the relation between relative humidity and static electricity. This study has progressed far enough to demonstrate a definite relation, and furthermore that static can be used as a basis for the prediction of changes in humidity.

[1] Excerpts of paper read at meeting of American Meteorological Society at Los Angeles, Calif., September, 1923.